Monitoring the Posidonia Meadows structure through underwater photogrammetry: a case study.

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***Abstract*—The Posidonia *oceanica* meadows represent a fundamental biological indicator for the assessment of the marine ecosystem state of health. They also cover an essential role in the conservation of coastal morphology. The composition, extent and structure of the meadows are conditioned by the biological characteristics of the plant itself and by the environment setting, considering the type and nature of the substrate, the geomorphology of the seabed, the hydrodynamics, depth and brightness of the scenario, the sedimentation speed, etc.**

In this work we present a methodology for the effective monitoring and mapping of the *Posidonia oceanica* meadows by means of underwater photogrammetry: the analysis made on their structure is further intended to verify the possibility of using the photogrammetry for the reliable characterization of the seabed and the classification of the vegetation coverage.

Keywords— 3D Modelling, Monitoring Operations, Posidonia oceanica, Underwater Photogrammetry

INTRODUCTION

The *Posidonia oceanica* has a fundamental role for the ecosystems: it is considered as a natural carbon sink, since its capacity of storing large amounts of carbon in its sediments over long periods [1]. Moreover, the "matte" of Posidonia constitutes a complex habitat in which various organisms can find nursery and protection [2]. The accurate monitoring of the Posidonia extension and growth over the years assumes then particular importance for the assessment of the biodiversity health status and its preservation.

In the past decades, the joint use of acoustic and optical data has proved to be a reliable tool to obtain high resolution thematic maps, which are further used for the preliminary characterization of marine phanerogams habitats. Moreover, direct measurement methods carried out by an underwater technical operator, and/or with video inspections and images, have always represented the most effective method for validating the data acquired with indirect instruments.

In the context of seabed investigations, the current direct sampling methodologies involve divers in the surveying operations to provide data for the assessment of the substrate coverage [3]. This is generally made through visual estimations performed by the operator on a circular area with a 5 meters-radius (measured with respect to a fixed point). This also allows for the definition of the percentage of plants extension, which is further compared with the presence of sand, dead "matte", rock, etc: this percentage defines the *coverage* of the bottom. Table 1 reports the different parameters for the visual estimations at sea: this operation is generally simultaneously performed by two operators and the average between their estimates provides then the coverage value [4].

This study proposes a photogrammetric approach for the investigation of the seabed at a high-definition level. More in detail, the underwater photogrammetry is here used to produce accurate visual estimates of the *Posidonia oceanica* meadows coverage, in line with the standard current methodologies [4]. In fact, the visual assessment made by an operator on a limited surface can also be performed on a larger area by analysing the point cloud obtained by the photogrammetric elaboration of the video-frames; the latter can be acquired by the divers or other means, as for example cameras mounted on Remoted Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs). The analysis of the point cloud also allowed to estimate with good accuracy the height and profile of a matte, using an open-source software for points management.

TABLE 1. VISUAL ESTIMATION PARAMETERS AT SEA.

Parameter	Measurement Unit
Meadow Continuity	1=continuous, 2=discontinuous
% Dead matte coverage	%
% Alive PO coverage	%
% Caluerpa racemosa	%
% Cymodocea nodosa	%
Substrate	1=rocks, 2=sand, 3=matte
Disturbance factors	1=yes; 2=none
Meadow composition	1=pure; 2=mixed
Non-native algae	1= Caluerpa racemosa;2= Caluerpa taxifolia; 3=both

This acquires particular importance in view of future bio-ecological operations involving reforestation interventions. In fact, studies carried out on transplanted areas show that Posidonia can take root with greater possibility on areas with the presence of dead matte [5]. In this regard, the combined use of our photogrammetric

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approach with conventional survey techniques could provide a reliable and useful mean to improve the knowledge of the matte extension, to further guide the reforestation interventions.

The next sections provide a brief overview on similar works made on the underwater monitoring, followed by some information on the technology and methodologies employed in our surveys. Details on the experiments are then given together with the obtained results, and some considerations conclude the work.

RELATED WORKS

As previously introduced, the monitoring of the Posidonia meadows is currently performed by divers who methodically acquire direct measurements of the limits, dimensions and erosion of the matte [6, 7]. This process has a great reliability but is limited by the operators dive time, the generally high costs and the campaign completion time. For this reason, many other supportive applications are tested to make these monitoring procedures cheaper while maintaining their reliability and accuracy.

Side Scan Sonar (SSS) and Multi-Beam Echo-Sounder (MBES) are considered as the most common acoustic methods for seafloor mapping and analysis; AUV-based methodologies can also be used to detect and map the *Posidonia oceanica* with good results on the windows extension, but some limitations related to the higher costs of deployment [8,9].

Structure-from-Motion (SfM) photogrammetry was initially developed and applied to terrestrial settings; by virtue of its greatly satisfying results, it has also been employed as an important tool for creating three dimensional models of underwater bathymetry and habitats [10,11]. Underwater photogrammetry allows the virtual reconstruction of 3D models and / or to obtain orthorectified photo assemblages (orthomosaics) of the sea floor, through the processing of a high number of images of the area of interest. These frames are generally acquired by a diver [12], by an AUV [13,14] or a ROV [15], or by a towed camera [16]. Important elements of this latter system include the integration of multiple cameras and a survey-grade Global Navigation Satellite System (GNSS).

Underwater photogrammetry is often associated with shallow waters monitoring, where positioning and measurement of targets with established positioning systems is still possible [17]. The use of dynamic positioning systems associated with ROVs can certainly be a good compromise, also in terms of precision of positioning data, as long as these systems can provide continuous and valid data for the entire duration of the navigation. Another fundamental aspect relates to the association of high-resolution images acquired with the cameras and the related positioning data; also in this case, the problem is usually solved by using highly specialized and expensive tools, which are unfortunately not always within the reach of researchers.

Following these works and considerations, we present a workflow of image acquisition and processing from underwater video footage at depths greater than 10 meters and the related photogrammetric approach for the 3D mapping of the study area. Other than integrating other video cameras to the ROV setting, we also used an Ultra-Short Base Line acoustic positioning system (USBL) tracking system specifically designed for small submarine and surface units (which integrates a magnetic compass and a pitch and roll sensors). Our results have been used to evaluate the quality of the mapping on areas with Posidonia meadows, providing measurable and classifiable data in 3D (especially in the case of matte). This approach demonstrates the potential of underwater photogrammetry in generating highly accurate biocenotic maps for any further research projects aimed at habitat conservation and protection.

MATERIALS AND METHODS

Study Area

The survey has been conducted in the marine area of the "Spiaggia Nera" in Maratea (PZ), Italy, in the month of May 2022 which is the period of maximum flowering of the *Posidonia oceanica.*

Two separated regions of interest have been individuated through the analysis of the bathymetrical data: (i) a sandy area characterized by a relevant presence of matte with a considerable height, at a depth of about 6-8 m and (ii) a surface with an important presence of biocoenosis, characterized by a sandy bottom interspersed with rocks and matte, at a depth of about 14 m.

Instrumentation

The ROV used for the investigations is the MINI ROV-UD 6-100 (Fig. 1), specifically designed to quickly perform a variety of basic underwater tasks: observation, inspection, exploration, and monitoring. Moreover, the following sensors are mounted on the ROV: (i) an integrated system with a 3-DOF gyroscope, a 3-DOF accelerometer and a 3-DOF magnetometer, (ii) an internal barometer, (iii) a pressure / depth & temperature sensor, (iv) a current and voltage sensor, (v) a system for leak detection.

Figure 1 - The Mini ROV-UD 6-100 used for the surveys.

For the scope of this survey, the Tritech's MicronNav positioning system (designed for small systems such as the VideoRay ROV) has been used. This system includes (i) a submarine MicronNav Transponder / Responder, (ii) a surface USBL transducer with integrated magnetic compass e pitch/roll sensors, (iii) a surface MicronNav 100 interface hub and operating software in control of a host PC / laptop; it has a tracking range of 500m and 150m in the horizontal and vertical direction respectively.

Three GoPro Hero, a 3+, an 8+ and a 9+ have been used for the video acquisition. The GoPro 8+ and 9+ have been mounted on the ROV, with the camera axis tilted of about

10° with respect to the horizon line; the GoPro 3+ has been instead used by the diver in a *face down* camera setting [16].

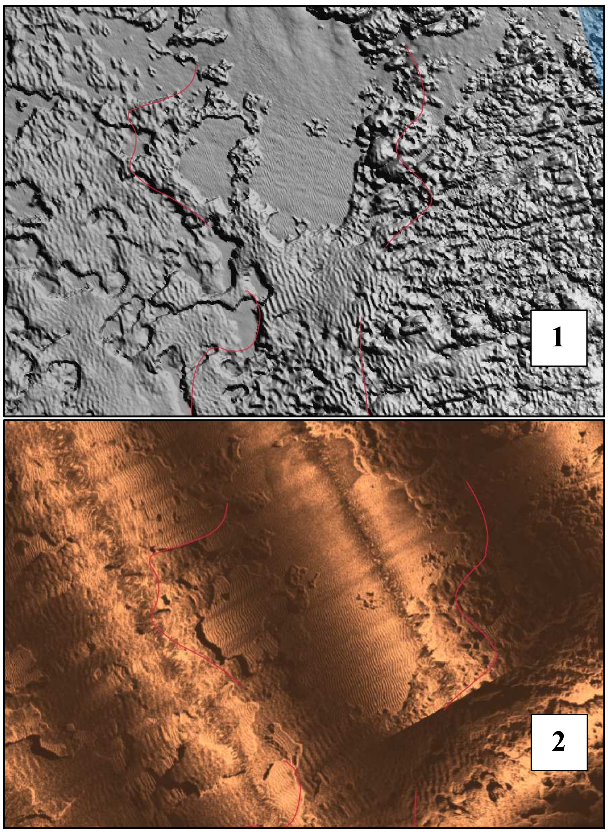

Figure 2 - Posidonia oceanica meadows, Maratea area: characterization of the seabed, DTM (1) and photomosaic processing (2), identification of mattes.

The three cameras were set at a resolution of 1920x 1080 - 12MP with a framerate of 59.94 fps.

Survey methodology

For the preliminary survey of the meadows extension, both direct and undirect surveys techniques have been employed. Firstly, a Multi Beam and a Side Scan Sonar have been used for the bathymetric data acquisition, which we processed to obtain the Digital Terrain model (DTM) and the lateral scan photomosaic (Fig. 2). These maps have been accurately studied to characterize the seabed and to identify the area of interest to further plan the joint diver/ROV mission.

This resulted in a series of transepts which have been navigated to acquire the video. To allow for the correct scaling of the 3D model, the diver positioned two cylindrical targets bars 1 meter long in two strategic points of the area to be monitored; these targets are painted in red and yellow for their easy identification in the elaboration phase.

Our study analyses (i) the transept SN2, made with the Go Pro Hero 8 acquired by the ROV at a 14m depth following the height of the matte, and (ii) the video of the transept ST7, acquired through by the diver Go Pro Hero 3 maintaining a distance from the seabed of about 3m. To assure the acquisition of superimposed images, a speed of about one knot has been kept constant during the navigation [16]. The acquisition and positioning software (PDS2000) integrated with the USBL allowed to track the ROV position during its navigation.

Experiments and Results

The videos have been fragmented to extrapolate the frames, which we then processed using a commercial software widely employed for photogrammetric applications: PIX4D (v. 4.6.4). It allowed to align the frames using classical Structure from Motion algorithms. As previously mentioned, the accurate identification on several frames of the two 1-meter bars allowed also to correctly scale the photogrammetric model. As a result, the ST7 transept (280 frames) generated a sparse cloud of 2204910 points, with a mean resolution on the seafloor of 2cm / pixel. The SN2 transept (688 frames), instead, produced a sparse cloud of 3971913 points, with a mean ground resolution of 4 cm / pixel.

We then created the dense point cloud, on which we applied a mesh for a clear distinction between Posidonia, opaque rock and sand (Fig. 3). The final point cloud has then been imported in the CloudCompare open-source software (v. 2.12.3) which allowed to color and classify the seabottom and to accurately dimension the Posidonia and the matte. Some preliminary results are here reported. We measured the seabottom extension on the 3D model obtained from the ST7 transept, which resulted in a length of 25 meters and a width of about 5 meters. We also clearly distinguished the presence of Posidonia, matte, sand and rock: there is a predominance of rocks, alternated with small sand banks from which the Posidonia extends up to about 1.4 meters. Figure 4 shows the 3D model of the SN2 transept with a well-defined vertical profile of the matte of about 2 meters. The foot of the matte does not show signs of undermining and there are areas with tufts of Posidonia oceanica scattered on the wall: a sign of the vitality of the meadow.

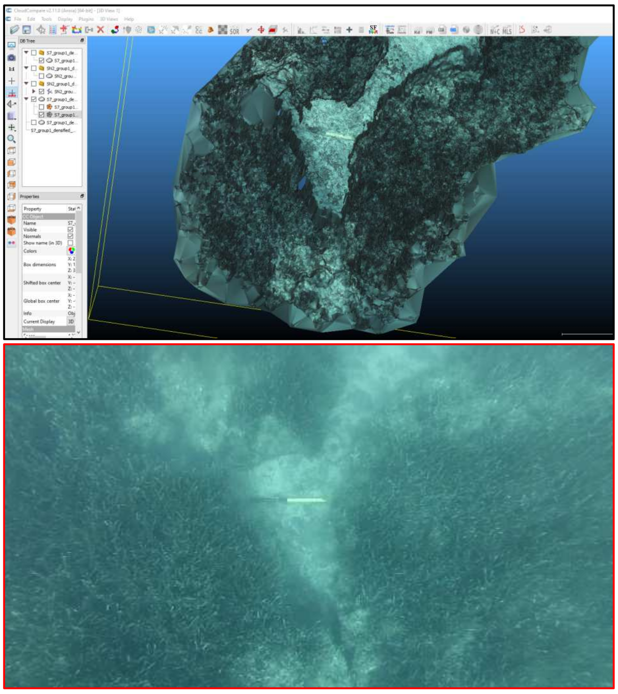

Figure 3 - Part of the points cloud and corresponding frame.

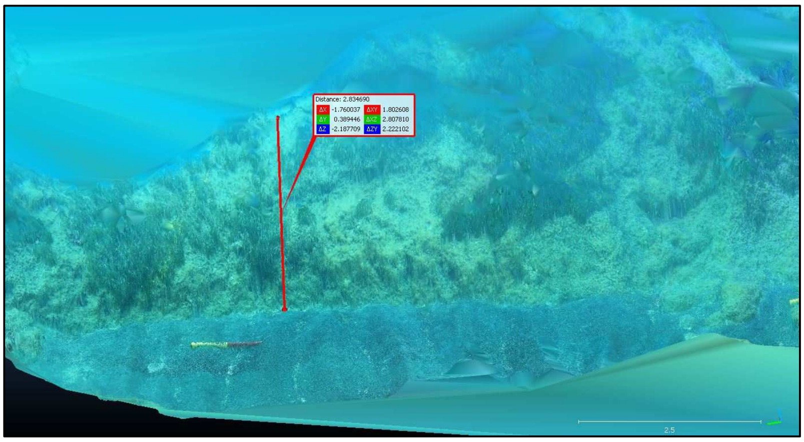

Figure 4 - 3D model of the SN2 transept showing the measure of the vertical profile of the matte.

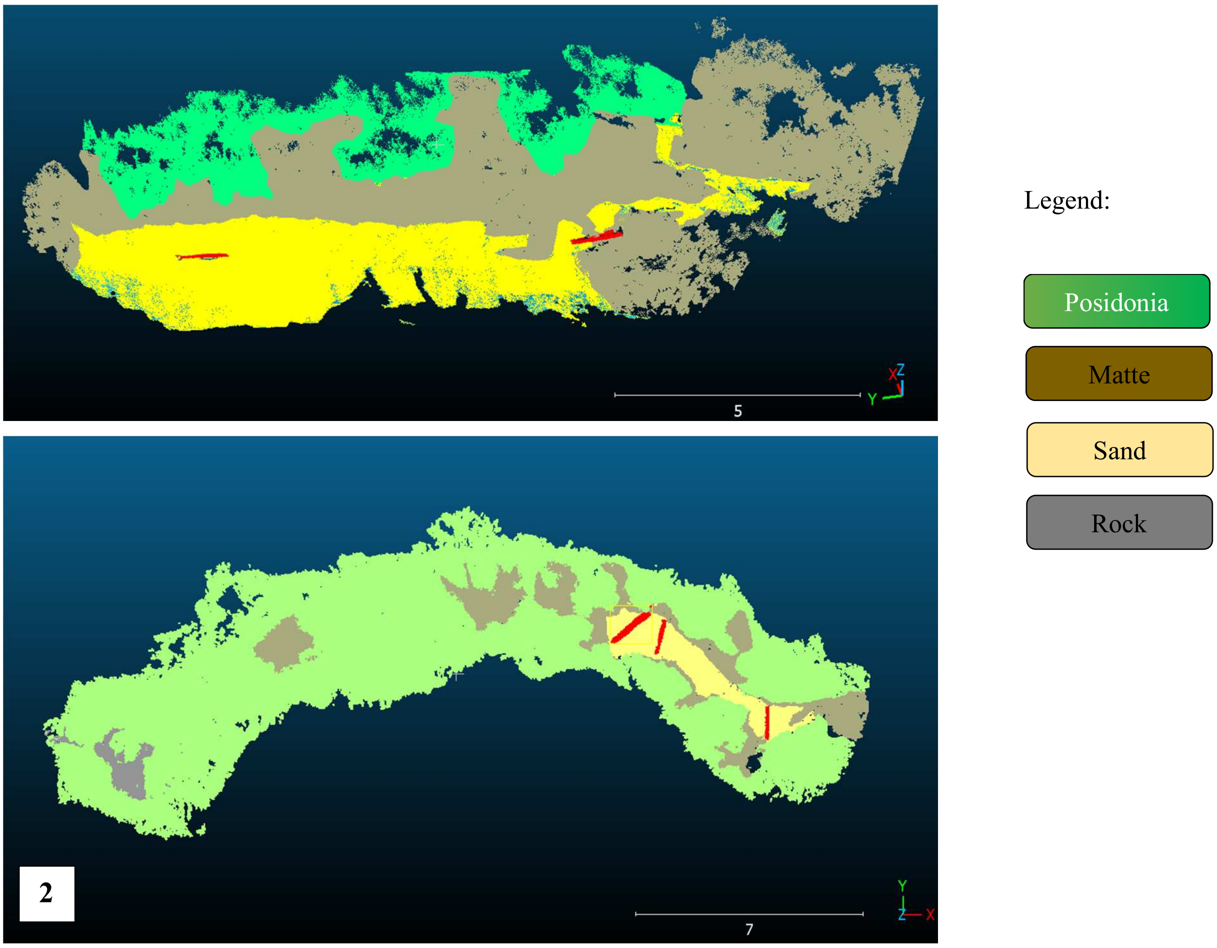

Figure 5 – Characterization of the SN2 (1) and ST7 (2) transepts on the basis of the identified layers. The targets are depicted in red.

TABLE 2. COVERAGE AREA ESTIMATION OF THE SN2 AND ST7 TRANSEPTS.

Transept	**Posidonia oceanica**		**Matte**		**Sand**		**Rock**		**Total coverage**
	[m^2]	(%)	[m^2]	(%)	[m^2]	(%)	[m^2]	(%)	[m^2]
SN2	55.422	26%	110.320	51%	50.217	23%	/	/	215.959
ST7	351.903	85%	45.469	11%	12.782	3%	5.416	1%	415.57

To correctly classify the coverage nature of the area of interest, the two point clouds have been segmented in CloudCompare. Using the masks, we identified the following layers: “matte”, “Posidonia”, “sand” and “rock”.

Fig. 5 shows the different classified areas for both the SN2 and the ST7 transepts, with Table 2 reporting the related coverage area in m^2 and in total percentage (%) of the area. These data will further allow to obtain information on the age of the Posidonia, confirming the potential of the employed techniques (ROV navigation and GoPro Cameras for the visual data acquisition) for the accurate characterization of the sea bottom and its coverage.

CONCLUSION

In this work, we present a photogrammetric application for the underwater monitoring, mapping and reconstruction of the Posidonia oceanica meadow. The use of Multibeam and Side Scan Sonar allowed to investigate the structural and morphological characteristics of the sea bottom, to further plan the survey to be performed by the ROV and diver.

The elaboration of the frames acquired by the GoPro Hero cameras (two on the ROV and one used by the operator) produced a point cloud which has been further scaled using the two sized targets strategically placed in the surveying area. We obtained an accurate reconstruction of the 3D model, on which we measured the dimensions of the Posidonia and the matte dead matte or other substrate present at the bottom. Moreover, the application of mesh on the dense point cloud allowed us to estimate the percentage of Posidonia coverage in the investigated area.

The dimensional study of the Posidonia mattes will allow to obtain quantifiable data for long-term monitoring; moreover, future works could aim at identifying suitable areas for the Posidonia transplants. Another aspect to consider is the possibility of creating a correlation between the size of the matte (vertical growth, definition of the percentage of dead or alive matte) and the potential of the matte to act as a biogeochemical sink (Blue Carbon).

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